Characterization of Turkish Coals: An example of International cooperation to develop a World Coal Quality Inventory (WoCQI).

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ABSTRACT

The U.S. Geological Survey (USGS) and the General Directorate of Mineral Research and Exploration in Turkey (Maden Tetkik ve Arama Genel Müdürlügü, MTA) are working together to provide a more complete understanding of the chemical properties of coals from major Turkish coal producing areas. The coals in Turkey formed in several different depositional environments at different geologic times and have different chemical properties. Turkish coal is produced mainly for use in power plants; households and industry use small amounts. All samples in this study were collected as bed channel samples. We analyzed of 144 coal samples (mostly low rank coals) for up to 54 elements and other coal properties using a variety of analytical techniques including inductively coupled plasma emission and mass spectrometry, instrumental neutron activation analysis, and various single element and ASTM procedures. Many of these Turkish coals are lignites and have trace-element concentrations similar to US lignites. However, maximum and/or average concentrations of Ni, Cr, As, U, Sb, and B in Turkish coals are higher in many regions of Turkey than the corresponding values found in either of the Gulf Coast or Fort Union basins, the two most productive lignite basins in the United States.

INTRODUCTION

Until recently, the Turkish economy has been growing rapidly and electrical energy demand is increasing approximately eight percent per year. Total installed electric capacity reached 23,500 MW by the end of 1998. Over half of this electric capacity is derived from fossil fuel energy including energy from coal (approximately 13,000 MW) and the remaining capacity (10,500 MW) is from other sources such as hydroelectric, geothermal and wind energy. The gross electricity generation reached approximately 111 billion kWh (1,786 kWh per capita) in 1998 (Dilli, 1999).

Coal is clearly important to the Turkish economy. The U.S. Geological Survey (USGS) and the General Directorate of Mineral Research and Exploration in Turkey (Maden Tetkik ve Arama Genel Müdürlügü, MTA) are working together to provide a more complete understanding of the chemical properties of coals from major Turkish coal producing areas. This study is part of the “Inventory of Technological and Chemical Properties of Turkish Lignites” project conducted by the MTA General Directorate to provide Turkey with information on their coals and the “World Coal Quality Inventory” (WoCQI) project designed to look at coal quality worldwide. The study reported here is intended to provide a broad regional overview of coal quality of coals currently mined in Turkey. Table 1 gives relative information on the coal reserves for each region.
Trace element analyses are important for more comprehensive description of coals and can be used in assessing the role of trace elements in technological behavior during combustion, by–product recovery after combustion, and environmental impacts of coal utilization. Early work on trace elements in Turkish coals using neutron activation analysis was reported by Ayanoglu and Gunduz (1978 a,b and c). Recently there has been more interest in trace elements in Turkish coal (Karayigit, et al.,1997,1999,

Table 1. Regional distribution of reserves and some properties of Turkish coals.

REGION	Surface area (Km^2)	Coal thickness (Max.-Min.) (m)	Depth (m)	Number of holes with coal	Number of holes without coal	Total number of holes	Distance between holes (m)	Total drilling length (m)	Total Reserves Million Tons
Western Turkey (North to South)									
MARMARA (THRACE)	219.80	0.10-5.10	0.0-331.6	794	301	1095	150-1200	98700	525.2
MARMARA (SOUTH)	161.19	0.05-39.75	0.0-828.0	851	308	1159	100-1500	235200	299.6
AEGEN	279.69	0.20-57.00	0.0-601.0	1955	396	2351	50-1950	361600	2014
Central Turkey (North to South)									
BLACKSEA (E and W)*	42.77	0.35-12.60	0.0-605.0	272	98	370	50-1000	106000	215.4
CENTRAL ANATOLIA	558.90	0.20-27.30	0.0-522.6	1036	342	1378	50-1500	168900	1325
MEDITERRANNEAN	25.28	0.60-18.20	0.0-378.0	52	33	85	100-1500	13790	362.6
Eastern Turkey (North to South)									
EAST ANATOLIA	184.85	0.10-26.05	0.0-800.0	1271	143	1414	65-2650	225800	3580
SOUTHEAST ANATOLIA	1.50	3.90-87.00	0.0-150.0	22	6	28	200-800	2164	53.09
TOTAL	**1473.97**	**0.05-87.00**	**0.0-828.0**	**6253**	**1627**	**7880**	**50-2650**	**1212000**	**8374**

*The East and West Black sea regions were combined into one region for this data set.

Data from Gökmen, V., Memikoğlu, O., Dağlı, M., Öz, D., Tuncalı, E., 1993, and Demirok, Y.,Uçakçıoğlu, A., 1993.

2000a,b,c, Palmer et al. 1999, Querol et al. 1997, 1999). These papers deal primarily with the composition of Turkish coals from specific regions.

COAL RESOURCES

Tertiary deposits (mainly Miocene) suitable for coal formation cover approximately 110,000 km^2 in Turkey. This area has been examined by MTA, and an area of 41,700 km^2 is interpreted to be promising for coal formation based on geologic mapping (at scales of 1:25000 and 1:10000). Drilling data from a total length of more than 1,212,000 meters showed the extent of the coal bearing formations to be 1470 km^2. The thickness of coal beds range from 0.05 to 87.0 meters. The maximum depth of coal bed from the surface is 828 meters and drill hole intervals range from 50 to 2650 meters. (Tuncalı,1995; Gökmen et al., 1993). These studies determined that 8.3 billion tons of low rank coal reserves in addition to 1.3 billion tons of hard coal (Demirok, 1993) are present in Turkey. The amount of proven recoverable reserves is 3.9 billion tons in 43 coal fields, on which feasibility studies were completed. Sixty six percent of these reserves are suitable for open-pit mining. The annual coal production in Turkey reached 67.3 million tons (61.7 million tons in state-operated mines and 5.6 million tons produced by the private sector) in 2000. Most of the coal produced (52.1 million tons) supplies the fuel for thermal power plants with a total capacity of 6,380 MW. The remaining coal is consumed by industry (7.3 million tons) and the public (6.6 million tons). Over one billion tons of coal has been produced since 1923. Regional distribution of coal reserves and other parameters such as surface area, thickness, depth, total length of drill holes etc., are given in Table 1.

SAMPLES AND EXPERIMENTAL METHODS

This work is part of two larger studies, one to assess the amounts and chemical properties of Turkish coal reserves and the other to obtain representative information on coal quality for the international coal database (WoCQI). A total of 144 samples (including 71 reported earlier by Palmer et al. (1999)) from nine different regions were collected from Turkey. For this study collected one channel sample per coal field in order to obtain data from as many areas as possible. Each sample was obtained from an active mine, and most active mines are represented. Although a single sample cannot represent a coal field, samples collected from several coal fields within a basin may provide information on regional variability. This preliminary study can be used as a basis for further detailed studies in individual coal fields. The number of coal samples analyzed from each region is given in Table 2. Figure 1 shows the sample locations. Generally partings thicker than 50cm were excluded in sample collection. In some cases, samples of thick beds were collected benches then recombined as composite samples using thickness weighted averages for each bench. The procedures used in this study were described by Palmer et al. (1999).

RESULTS AND DISCUSSION

Due to space limitations for this paper, only average data for each coal region in Turkey is reported here. The individual sample values on several moisture bases, and stratigraphic data can be found at the web site http://geode.usgs.gov. Because most of the Turkish coals are low rank coals (many are lignites), this paper compares and contrasts them with coals found in the Gulf Coast and the Fort Union regions of the US, which are mostly lignites. Table 2 gives average results for each coal region for moisture content (as-received and residual), ash yields (525 ^oC and 815 ^oC), volatile matter, fixed carbon, sulfur in the whole

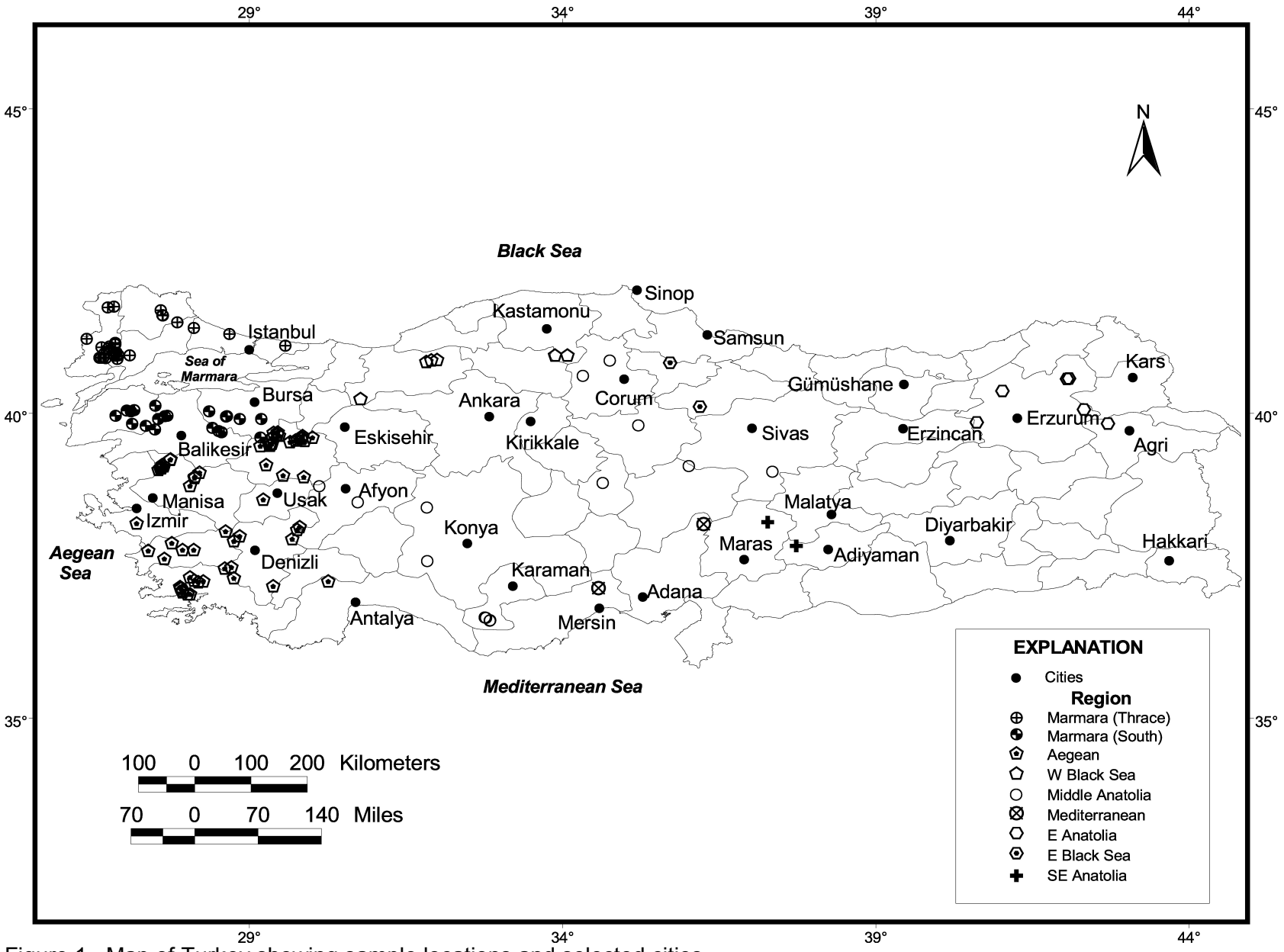

Figure 1. Map of Turkey showing sample locations and selected cities.

Table 2. Summary by region in Turkey of moisture, ash, volatile matter, fixed carbon, sulfur, and calorific values on an air-dried basis except as noted.

	Moisture as Received percent	Moisture percent	Ash (815 °C) percent	Ash USGS (525 °C) percent	Volatile Matter percent	Fixed Carbon percent	Combust-able Sulfur* percent	Sulfur in ash percent	Total Sulfur percent	Net Calorific Value calories	Gross Calorific Value calories
Marmara Region (including Thrace Basin)											
Average	31.8	10.6	20.6	22.5	32.8	36.0	2.82	0.78	3.50	4077	4325
Std. deviation	10.0	2.5	6.5	7.3	6.2	5.3	2.3	0.5	2.3	409.1	422.5
Maximum	47.0	16	34.1	36.7	45.5	53.8	8.6	2.74	9.61	4952	5210
Minimum	16.75	6.6	11.25	8.3	14.5	28.5	0.2	0.05	0.69	3345	3558
N	28	28	28	28	28	28	27	28	28	28	28
Marmara Region (Southern part)											
Average	24.2	7.1	27.1	28.3	32.2	33.6	3.2	0.40	3.4	4157	4384
Std. deviation	8.5	2.5	12.5	12.0	5.7	7.1	1.9	0.3	1.8	834	865
Maximum	39.7	11.4	47.5	50.3	41.6	44.1	6.64	1.26	6.86	5439	5713
Minimum	6.09	1.6	9.1	11.5	23.7	21.2	0.37	0.01	0.24	2551	2721
N	20	20	20	20	20	20	19	20	20	20	20
Aegean Region											
Average	24.4	7.7	25.8	29.4	34.8	31.7	2.9	1.0	3.8	4031	4258
Std. deviation	10.5	3.0	10.6	13.2	5.5	7.5	2.1	0.8	2.2	803	824
Maximum	41.2	14	58.4	69.4	44.5	47.4	9.5	3.7	9.9	5728	5958
Minimum	3.16	1.2	6.39	5.2	9.6	11.64	0.01	0.04	0.44	1847	2009
N	64	64	64	64	64	64	64	64	64	64	64
Western Black Sea Region											
Average	17.4	6.8	22.1	24.7	36.1	35.0	5.4	0.7	6.1	4364	4598
Std. deviation	7.6	1.7	14.3	16.1	9.6	6.6	2.9	0.5	2.9	1242	1286
Maximum	30.9	8.7	47.8	54.1	46.7	41.0	7.7	1.3	8.9	5623	5884
Minimum	8.9	3.9	11.6	12.8	21.7	22.9	0.8	0.1	1.9	2261	2417
N	6	6	6	6	6	6	6	6	6	6	6
Central Anatolian Region											
Average	27.2	9.0	21.8	24.5	35.9	33.2	2.4	1.2	3.6	4104	4328
Std. deviation	16.9	4.0	11.8	12.4	4.2	8.2	1.7	0.7	1.7	781	797
Maximum	57.7	13.8	47.8	51.6	41.0	49.8	6.31	2.36	6.45	6075	6322
Minimum	3.36	2.3	5.88	6.6	27.3	21.0	0.08	0.14	1.1	3011	3170
N	14	14	14	14	14	14	14	14	14	14	14
Mediterranean Region											
Average	33.6	11.0	40.4	40.9	30.0	18.6	2.7	2.1	4.8	2440	2622
Std. deviation	13.0	4.1	16.6	10.6	0.1	12.6	1.6	0.3	1.3	1054	1093
Maximum	42.7	13.9	52.1	48.4	30.1	27.6	3.8	2.3	5.7	3185	3395
Minimum	24.4	8.1	28.6	33.4	29.9	9.7	1.6	1.9	3.9	1695	1849
N	2	2	2	2	2	2	2	2	2	2	2
East Anatolian Region											
Average	17.2	4.4	31.0	33.5	34.3	30.4	1.4	0.9	2.3	4061	4261
Std. deviation	15.3	2.5	12.4	14.5	4.8	11.5	1.0	0.7	1.2	1445	1473
Maximum	38.5	7.2	54.6	61.5	39.3	41.9	2.82	1.84	4.4	5333	5538
Minimum	1.2	0.7	19.5	20.4	26.4	13.2	0.05	0.04	1.1	1640	1778
N	6	6	6	6	6	6	6	6	6	6	6
Eastern Black Sea Region											
Average	11.9	4.3	30.3	33.4	34.2	31.3	1.4	1.4	2.8	4073	4265
Std. deviation	4.6	1.1	4.9	2.3	7.7	3.9	0.8	1.4	2.2	15	4
Maximum	15.1	5.1	33.7	35.0	39.6	34.0	2.0	2.4	4.3	4083	4267
Minimum	8.7	3.5	26.9	31.7	28.7	28.5	0.9	0.3	1.2	4062	4262
N	2	2	2	2	2	2	2	2	2	2	2
Southeast Anatolian Region											
Average	49.5	12	27.5	36.2	37.4	23.1	1.23	1.64	2.87	3236	3474
Std. deviation	0.7	2.0	3.9	ND	1.7	0.2	0.2	0.3	0.6	177	185
Maximum	50.0	13.4	30.2	36.2	38.7	23.2	1.4	1.9	3.3	3361	3604
Minimum	49.1	10.6	24.7	36.2	36.2	23.0	1.07	1.4	2.47	3111	3343
N	2	2	2	1	2	2	2	2	2	2	2

* Combustible Sulfur= Total Sulfur-Sulfur in ash N= number of samples. Std.=standard

coal, ash combustible sulfur and the net and calorific values (in calories). Three regions (the Eastern Black Sea Region, the Mediterranean and the Southeast Anatolian Region) have two or fewer values and will not be compared in this study, but the data are reported in the Tables 2, 3 and 4. Except for moisture content, all values are on a residual moisture (as-dried) basis in Table 2 and on an as-determined whole-coal basis for Tables 3 and 4. The as-received moisture contents were as high as 57.7 percent, but many of the samples had less than 20 percent moisture and some were even less than 10 percent. Minimum values for as-received moisture content were less than 20 percent for all regions compared. These compare with average moisture values of 34.8 and 38.3 percent for the 139 Gulf Coast samples and the 205 Fort Union lignite samples determined by Bragg et al. (1997). Although the coals in these regions of Turkey are generally considered to be lignite, low moisture contents indicate that some samples may be higher rank than lignite or that some moisture was lost prior to as-received moisture analysis.

Table 3 shows the results for each region for the average major and minor elements on a dry basis. For most elements there is a large range of concentrations within each region that probably reflects the range of ash yields. The average ash values (525 ^{o}C and 815 ^{o}C), and the total sulfur for all regions in Turkey (Table 2) were higher than the average ash content (750 ^{o}C) and the total sulfur reported by Bragg (1997) of 12.8 and 8.6 percent ash and 1.04 and 0.98 percent sulfur for the Gulf Coast and Fort Union lignites, respectively.

Except for Na, values of the major elements are similar to those reported by Bragg et al. (1997) for the U.S. coal samples from the Gulf Coast and Fort Union regions. The average Na contents of the Turkish coal samples range from 0.04 to 0.14 wt. percent, and are similar to 0.06 wt. percent determined for the Gulf Coast region. However, the average Na content for Fort Union region of 0.44 wt. percent is considerably higher than the Turkish coals.

The average, standard deviation, maximum, and minimum concentration values of trace elements in coal samples from the Turkish coal regions are reported in Table 4. Most trace-element data are similar to data from the Gulf Coast and Fort Union regions of the U.S. Although the data are too sparse to warrant detailed discussion of inter- and intra-basin variations, some trends are noted. The concentration of Ni in Turkish coal samples is very high (up to 1681 ppm) compared to a maximum of 77 in the Gulf Coast and 84 in the Fort Union region. The average value for Ni in most Turkish coal regions is higher than the highest Ni values found in U.S. lignites. The Ni concentration values increase from north to south in western Turkey and are high in the Black Sea regions.

The Turkish coal samples generally have higher Cr contents (region averages are 33 to 302 ppm) compared to 14 ppm for the Gulf Coast region and 6 ppm in the Fort Union region. The maximum value of Cr that we determined was 586 ppm. The average concentration values of Aegean Region (Table 4) are greater than the maximum values in the U.S. In western and eastern Turkey, the average Cr concentration values increase from north to south. However, this trend is not observed in the central part of the country.

The average concentrations of As are 28 to 197 with a maximum of 686 ppm. These values are greater than the maximum concentration found in the Gulf Coast region (22 ppm) and are higher than the average of Fort Union region (8.4 ppm). Like Cr and Ni, As generally increases from north to south in Western Turkey. Seven regions had at least one sample with As concentrations greater than 150 ppm. Karayigit et al. (2000b) found As concentrations as high as 3854 ppm (averaging 833 ppm) in borehole samples from the Gölker coal field in the Aegean region. A sample in a nearby mine in our study had 475 ppm of As.

Average U concentrations generally increase from northern Turkey to southern Turkey. All average U concentrations were higher than average U concentrations of the US Gulf Coast (1.5 ppm) and the Fort Union (2.2 ppm) regions.

The average Sb concentration in the Aegean region (4.8 ppm) was higher than the maximum value (2.8 ppm) in the US Gulf Coast region. The highest Sb value determined in Turkey was 42 ppm. The average Sb concentrations in each Turkish region exceeded or were nearly equal to the average Sb concentrations for the US lignite regions. Karayigit et al. (2000b) also found high Sb concentrations up to 2347 ppm (averaging 134 ppm) in the Gölker coal field. The highest Sb value in our study (42 ppm) came from a nearby mine.

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Table 3. Maximum, minimum and average concentrations of major and minor elements in Turkey by region on a dry basis.

	Na	Mg	Al	Si	P	K	Ca	Ti	Fe	Ba
	%	%	%	%	%	%	%	%	%	%
Marmara Region (including Thrace Basin)										
Average	0.17	0.60	2.0	4.4	0.013	0.30	1.10	0.088	3.1	0.010
Std. deviation	0.14	0.24	1.1	2.5	0.009	0.21	0.55	0.048	2.1	0.006
Maximum	0.52	1.0	3.7	8.74	0.039	0.71	3.0	0.18	8.84	0.026
Minimum	0.014	0.096	0.42	0.42	0.0015	0.020	0.20	0.011	0.44	0.0017
N	28	28	28	28	28	28	28	28	28	28
Marmara Region (Southern part)										
Average	0.090	0.39	2.5	6.6	0.020	0.37	0.92	0.102	1.83	0.017
Std. deviation	0.083	0.35	1.18	4.2	0.0132	0.37	0.50	0.049	0.98	0.013
Maximum	0.34	1.28	5.3	18	0.048	1.17	2.07	0.220	4.5	0.064
Minimum	0.006	0.057	0.36	0.85	0.0046	0.039	0.051	0.0146	0.57	0.0025
N	20	20	20	20	20	20	20	20	20	20
Aegean Region										
Average	0.087	0.65	2.5	5.5	0.024	0.40	2.5	0.129	2.4	0.016
Std. deviation	0.087	0.4	1.6	3.9	0.020	0.37	3.0	0.147	1.4	0.011
Maximum	0.44	2.0	6.7	19.1	0.105	1.91	13.4	1.07	5.6	0.039
Minimum	0.010	0.115	0.41	0.58	0.0025	0.045	0.198	0.015	0.43	0.00041
N	64	64	64	64	64	64	64	64	64	64
Western Black Sea Region										
Average	0.42	0.37	1.85	5.28	0.021	0.23	1.32	0.095	3.08	0.010
Std deviation	0.72	0.27	1.92	6.02	0.016	0.17	0.96	0.083	1.56	0.010
Maximum	1.82	0.81	5.1	15.7	0.051	0.49	2.8	0.20	5.5	0.029
Minimum	0.010	0.14	0.37	0.97	0.009	0.077	0.19	0.021	1.27	0.0033
N	6	6	6	6	6	6	6	6	6	6
Central Anatolian Region										
Average	0.13	0.50	2.0	4.2	0.022	0.24	2.5	0.095	2.3	0.012
Std. deviation	0.17	0.28	1.5	3.4	0.017	0.31	1.4	0.087	1.6	0.013
Maximum	0.66	1.21	5.0	12.9	0.061	1.23	5.4	0.35	6.1	0.055
Minimum	0.0066	0.066	0.56	1.12	0.0027	0.035	0.50	0.020	0.53	0.0019
N	14	14	14	14	14	14	14	14	14	14
Mediterranean Region										
Average	0.040	0.74	3.4	7.6	0.088	0.60	2.8	0.17	5.59	0.020
Std. deviation	0.0039	0.15	2.4	4.5	0.076	0.51	1.2	0.12	0.66	0.0047
Maximum	0.043	0.84	5.1	10.8	0.14	0.96	3.7	0.26	6.1	0.023
Minimum	0.037	0.64	1.7	4.4	0.034	0.24	2.0	0.093	5.1	0.017
N	2	2	2	2	2	2	2	2	2	2
East Anatolian Region										
Average	0.14	0.73	2.09	9.49	0.02	0.31	1.83	0.10	2.18	0.012
Std. deviation	0.08	0.95	1.59	4.00	0.02	0.34	1.37	0.09	1.38	0.0065
Maximum	0.29	2.60	5.04	16.51	0.05	0.98	4.13	0.27	4.34	0.024
Minimum	0.07	0.08	0.89	5.98	0.00	0.04	0.20	0.04	0.63	0.0060
N	6	6	6	6	6	6	6	6	6	6
Eastern Black Sea Region										
Average	0.022	0.74	1.80	8.782	0.027	0.17	2.80	0.081	1.69	0.012
Std. deviation	0.0068	0.58	1.5	5.5	0.024	0.12	2.8	0.055	0.88	0.0053
Maximum	0.027	1.15	2.9	12.6	0.044	0.253	4.7	0.120	2.31	0.015
Minimum	0.017	0.33	0.71	4.9	0.0102	0.080	0.86	0.042	1.07	0.0079
N	2	2	2	2	2	2	2	2	2	2
Southeast Anatolian Region										
Average	0.066	0.54	2.57	5.70	0.09	0.32	4.92	0.18	1.68	0.020
Std. deviation	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Maximum	0.066	0.54	2.57	5.70	0.09	0.32	4.92	0.18	1.68	0.020
Minimum	0.066	0.54	2.57	5.70	0.09	0.32	4.92	0.18	1.68	0.020
N	1	1	1	1	1	1	1	1	1	1
Gulf Coast Region (Bragg et al., 1997)										
Average	0.06	0.21	1.5	3.9	0.031	0.1	1.3	0.13	0.94	0.018
Maximum	0.85	0.48	3.8	10	0.13	0.66	3.2	0.74	4.5	0.130
Fort Union (Bragg et al., 1997)										
Average	0.41	0.36	0.62	1.6	0.029	0.06	1.2	0.5	0.75	0.068
Maximum	1.1	0.63	2.9	10	0.098	0.51	2.9	0.53	2.8	1.300

Std. = Standard, N=number of samples analysed.

Table 4. Maximum, minimum and average concentrations of trace elements in Turkey by region on a dry basis.

	Li	Be	B	Sc	V	Cr	Mn	Co	Ni	Cu
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Marmara Region (including Thrace Basin)										
Average	13	1.2	174	5.2	45	48	75	7.4	59	18
Std. deviation	7.1	0.52	101	2.6	21	24	34	3.9	29	9.8
Maximum	26	2.7	439	9.7	82	85	167	19	110	48
Minimum	1.3	0.51	43	1.0	11	11	15	1.4	4.1	3.9
N	28	28	28	28	28	28	28	28	28	28
Marmara Region (Southern part)										
Average	23	1.6	341	5.8	79	66	184	15	198	15
Std. deviation	26	0.93	260	3.4	49	87	153	15	342	7.0
Maximum	117	4.1	763	15	202	288	691	55	1027	27
Minimum	4.6	0.31	32	1.4	16	9.3	29	2.3	9.0	4.2
N	20	20	20	20	20	20	20	20	20	20
Aegean Region										
Average	21	1.7	275	5.8	77	116	132	13	226	26
Std. deviation	22	1.2	256	4.3	53	111	98	11	333	22
Maximum	138	6.6	1308	24	283	586	440	55	1681	109
Minimum	1.8	0.17	24	0.96	8.6	8.2	16	0.95	6.2	3.1
N	64	60	64	63	64	64	64	64	64	64
Western Black Sea Region										
Average	5.5	1.2	271	3.6	78	52	112	10.4	201	21
Std. deviation	5.2	1.1	141	3.7	49	47	102	5.9	154	15
Maximum	14.4	3.1	544	10	166	124	305	17.4	483	45
Minimum	1.4	0.4	157	0.7	22	15	20	3.1	41	8.2
N	6	6	6	6	6	6	6	6	6	6
Central Anatolian Region										
Average	9.8	0.7	117	3.1	53	33	88	5.4	78	14
Std. deviation	7.7	0.8	98	1.9	29	16	54	3.2	71	8.7
Maximum	24	3.1	435	6.8	99	62	194	11	255	33
Minimum	1.7	0.2	51	0.4	6	3.9	29	1.1	3.2	1.6
N	14	12	14	14	14	14	14	14	14	14
Mediterranean Region										
Average	29	1.1	132	5.2	74	63	56	7.8	80	12
Std. deviation	31	0.5	89	3.5	57	17	22	3.6	6.6	12
Maximum	51	1.5	195	7.7	115	75	72	10.4	84	20
Minimum	6.6	0.8	68	2.8	34	51	40	5.3	75	4.0
N	2	2	2	2	2	2	2	2	2	2
East Anatolian Region										
Average	8.2	1.0	265	4.5	93	38	138	6.8	91	27
Std. deviation	7.6	0.4	271	4.2	67	34	73	6.6	82	29
Maximum	23	1.4	806	11.8	194	105	210	19	231	81
Minimum	2.3	0.4	64	1.4	34	11	20	1.3	12	8.6
N	6	4	6	5	6	6	6	6	6	6
Eastern Black Sea Region										
Average	15	0.47	198	3.3	35	81	156	11	178	17
Std. deviation	17	ND	17	1.6	1.6	85	114	5.2	199	12
Maximum	27	0.47	210	4.5	36	141	236	15	319	26
Minimum	2.6	0.47	186	2.2	34	20	75	7.3	37	8.7
N	2	1	2	2	2	2	2	2	2	2
Southeast Anatolian Region										
Average	22	0.81	45	6.0	201	302	93	6.5	60	18
Std. deviation	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Maximum	22	0.81	45	6.0	201	302	93	6.5	60	18
Minimum	22	0.81	45	6.0	201	302	93	6.5	60	18
N	1	1	1	1	1	1	1	1	1	1
Gulf Coast Region (Bragg et al., 1997)										
Average	10	2.0	115	4.5	32	14	150	4.5	10	20
Maximum	44	11	440	12	99	46	940	30	77	69
Fort Union Region (Bragg et al., 1997)										
Average	3.5	0.92	130	2.0	11	6.8	84	2.7	4	6.9
Maximum	33	16	600	14	110	64	670	68	84	78

Std.=Standard, N=Number of samples analyzed

Table 4 (continued). Maximum, minimum and average concentrations of Trace elements in Turkey by region on a dry basis.

	Zn ppm	Ga ppm	Ge ppm	As ppm	Se ppm	Rb ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm
Marmara Region (including Thrace Basin)										
Average	41	5.2	2.4	28	0.9	26	232	9.1	29	2.7
Std. deviation	38	2.4	3.3	34	0.5	18	115	7.5	17	1.5
Maximum	160	10.1	18.1	154	2.6	54	501	46	75	6.8
Minimum	7.8	1.0	0.5	3.5	0.1	1.1	50.2	4.5	6.5	0.92
N	28	28	28	28	26	28	27	28	28	26
Marmara Region (Southern part)										
Average	46.7	7.1	11	67	0.81	24	178	8.1	39.0	6.3
Std. deviation	56.2	3.4	8.0	90	0.63	24	142	3.8	15.5	3.7
Maximum	270.9	15.7	37	346	2.3	81	643	16.5	82.6	17.8
Minimum	8.7	1.5	0.3	8.7	0.22	2.8	79	2.2	8.4	0.6
N	20	20	19	20	11	20	20	20	20	20
Aegean Region										
Average	42	7.5	4.4	81	3.1	33	201	11	52	5.0
Std. deviation	29	5.1	6.6	132	4.9	33	180	8.4	44	3.7
Maximum	135	23	33	686	27	210	862	38	179	21
Minimum	6.4	1.1	0.1	2.0	0.1	4.1	2.8	1.3	4.0	0.3
N	64	64	59	64	59	64	63	54	40	59
Western Black Sea Region										
Average	46	3.6	8.6	109	3.6	10.1	207	5.2	44	2.8
Std. deviation	46	3.1	16	89	2.4	9.8	122	3.1	22	2.8
Maximum	131	8.2	42	228	6.8	26	416	10.5	83	7.3
Minimum	15	0.91	0.57	19	0.74	3.2	98	1.6	22	0.5
N	6	6	6	6	6	6	6	6	6	6
Central Anatolian Region										
Average	39	4.0	1.2	71	2.2	13.1	400	4.2	31	2.4
Std. deviation	31	2.7	1.0	131	1.3	8.7	309	2.8	22	2.0
Maximum	128	11.5	4.0	509	5.1	29.7	1289	13	76	8.5
Minimum	13	1.2	0.3	5.4	0.4	2.1	76	1.0	4.5	0.6
N	14	14	14	14	14	14	14	14	14	14
Mediterranean Region										
Average	92	8.0	7.1	197	3.1	41	295	9.6	64	6.6
Std. deviation	59	5.6	5.7	1.1	2.1	35	61	5.8	45	5.5
Maximum	134	12	11	197	4.6	65	338	14	96	10.5
Minimum	50	4.0	3.1	196	1.6	16	252	5.5	32	2.7
N	2	2	2	2	2	2	2	2	2	2
East Anatolian Region										
Average	31	4.2	2.0	60	0.78	18	251	4.3	38	2.3
Std. deviation	20	3.3	2.2	63	0.50	18	125	2.7	25	1.6
Maximum	62	10.4	6.3	173	1.5	52	448	9.4	86	5.2
Minimum	7.0	1.8	0.7	12	0.26	4.7	109	1.6	15	1.1
N	6	6	6	6	6	6	6	6	6	6
Eastern Black Sea Region										
Average	51	4.1	1.6	3.8	4.9	13	279	11	29	1.7
Std. deviation	15	3.3	0.4	0.5	1.8	11	65	12	27	1.5
Maximum	62	6.4	1.9	4.1	6.2	20	325	19	48	2.8
Minimum	41	1.7	1.3	3.5	3.6	4.8	232	2.8	9.5	0.60
N	2	2	2	2	2	2	2	2	2	2
Southeast Anatolian Region										
Average	48	8.9	4.0	40	19	20	201	11	45	8.1
Std. deviation	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Maximum	48	8.9	4.0	40	19	20	201	11	45	8.1
Minimum	48	8.9	4.0	40	19	20	201	11	45	8.1
N	1	1	1	1	1	1	1	1	1	1
Gulf Coast Region (Bragg et al., 1997)										
Average	19	6.7	4.4	4.3	5.5	19	244	14	57	5.8
Maximum	200	22	36	22	14	63	1100	100	240	31
Fort Union Region (Bragg et al., 1997)										
Average	11	3.1	2.5	8.4	0.79	ND	334	6.4	22	2.4
Maximum	170	16	13	63	3.4	ND	1300	84	160	11

Std. Standard; N= number of samples analyzed

Table 4. Maximum, minimum and average concentrations of Trace elements in Turkey by region on a dry basis.

	Mo	Cd	Sn	Sb	Cs	Hg	Tl	Pb	Th	U
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Marmara Region (including Thrace Basin)										
Average	3.1	0.10	2.0	0.81	2.5	0.09	0.86	6.81	4.12	2.38
STDEV	1.9	0.05	0.69	0.35	1.6	0.04	0.58	3.99	1.99	1.42
Max	7.0	0.22	3.0	1.43	5.3	0.18	2.01	18.63	8.59	6.55
Min	0.50	0.06	0.92	0.27	0.06	0.03	0.25	1.18	1.28	0.37
	28	10	12	22	28	27	16	27	28	28
Marmara Region (Southern part)										
Average	6.2	0.26	1.7	1.4	8.5	0.12	0.73	12.2	9.6	6.9
STDEV	3.7	0.24	0.7	1.1	12	0.15	0.40	7.8	6.2	4.6
Max	14.6	0.54	2.6	4.1	41	0.67	1.8	37	29	19
Min	1.5	0.05	1.0	0.5	1.1	0.03	0.13	2.6	1.5	1.1
Count	20	4	4	16	20	18	11	19	18	20
Aegean Region										
Average	14	0.42	2.1	4.8	6.8	0.15	1.1	12	7.1	21
STDEV	15	0.60	1.1	7.8	9.4	0.10	1.5	10	4.9	20
Max	76	3.5	4.8	42	51	0.66	7.4	59	23	132
Min	0.9	0.015	0.35	0.22	0.5	0.03	0.0	1.3	1.0	1.6
Count	64	47	30	60	64	62	33	61	56	64
Western Black Sea Region										
Average	12.2	0.13	1.2	1.5	1.0	0.10	0.20	5.0	5.6	4.1
STDEV	8.3	0.09	1.0	1.3	1.2	0.03	0.12	5.2	3.0	3.2
Max	22.4	0.26	3.2	3.4	2.7	0.14	0.39	15.1	7.7	9.5
Min	3.1	0.04	0.5	0.3	0.2	0.07	0.09	1.4	3.4	0.9
Count	6	6	6	6	6	6	6	6	2	6
Central Anatolian Region										
Average	15	0.18	1.9	1.4	2.4	0.10	1.0	7.4	7.5	14
STDEV	16	0.15	1.8	1.4	2.8	0.08	2.0	8.1	9.4	12
Max	59	0.53	6.9	4.4	11.5	0.36	7.3	34	24	37
Min	1.1	0.03	0.6	0.2	0.2	0.04	0.1	1.9	2.1	0.8
Count	14	14	12	14	14	14	14	14	5	14
Mediterranean Region										
Average	36	0.47	3.0	2.5	8.9	0.079	1.0	15	ND	22
STDEV	32	0.23	ND	0.4	10.1	0.004	0.6	10	ND	1.9
Max	59	0.63	3.0	2.7	16.1	0.081	1.4	22	ND	24
Min	13	0.30	3.0	2.2	1.8	0.076	0.6	7.8	ND	21
Count	2	2	1	2	2	2	2	2	ND	2
East Anatolian Region										
Average	7.6	0.12	1.8	1.3	1.2	0.11	0.45	4.6	3.9	3.8
STDEV	5.0	0.08	1.2	0.9	0.8	0.09	0.42	2.6	1.9	6.0
Max	15.4	0.24	3.1	2.7	2.6	0.29	1.19	9.1	5.2	15.9
Min	1.8	0.04	0.7	0.2	0.5	0.05	0.05	1.9	2.5	0.7
Count	6	5	3	6	6	6	6	6	2	6
Eastern Black Sea Region										
Average	1.6	0.25	1.34	0.25	1.20	0.09	0.18	5.2	2.9	1.8
STDEV	0.3	0.21	ND	0.16	1.08	0.04	0.16	6.0	ND	1.8
Max	1.8	0.40	1.34	0.36	1.96	0.12	0.29	9.5	2.9	3.0
Min	1.41	0.10	1.34	0.13	0.43	0.06	0.06	1.0	2.9	0.47
Count	2	2	1	2	2	2	2	2	1	2
Southeast Anatolian Region										
Average	19	0.32	ND	0.81	2.1	ND	ND	4.0	4.8	17.9
STDEV	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Max	19	0.32	ND	0.81	2.1	ND	ND	4.0	4.8	17.9
Min	19	0.32	ND	0.81	2.1	ND	ND	4.0	4.8	17.9
Count	1	1	ND	1	1	ND	ND	1	1	1
Gulf Coast Region (Bragg et al., 1997)										
Average	2	0.22	3.4	0.87	ND	0.22	1.1	8.3	4.9	2.3
Max	8.5	2.1	21	2.8	ND	1.0	2.3	29	24	17
Fort Union Region (Bragg et al., 1997)										
Average	3.8	0.11	0.51	0.58	ND	0.13	0.77	3.7	2.2	1.5
Max	280	2.7	1.3	7.3	ND	1.2	2.1	13	12	13

Std. = Standard; N= number of samples analysed.

Most Turkish lignite regions have higher B concentrations on average than average U.S. lignite regions (115-130 ppm). The maximum concentration of B in the Turkish coal samples is 1308 ppm. This valueis higher than the 600 ppm maximum for the U.S. lignite regions

CONCLUSIONS

There is an abundant supply of coal (mostly lignite) in Turkey that can be used for electric power generation. Total reserves of over 8 billion tons should help provide increasing power capacity for years. Generally these coals have trace-element concentrations similar to those of U.S. lignites. However, the concentrations of Ni, Cr, As, U, and Sb in Turkish coals are higher than in U.S. lignites.

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REFERENCES

ASTM, 2000 Annual book of ASTM Standards, Section 5 petroleum products, lubricants and fossil fuels, Gaseous fuels; Coal and Coke, vol. 05.06 American Society of Testing Materials, 622 p.

Ayanoğlu, S.F. and Gündüz, G., 1978a, Neutron activation analysis of Turkish coals; I, Elemental contents. Journal of Radioanalytical Chemisty v. 43 (1) pp. 155-157.

Ayanoğlu, S.F. and Gündüz, G., 1978b, Neutron activation analysis of Turkish coals; II, Analysis of ashes and the effects of burning conditions on percent transference. Journal of Radioanalytical Chemisty v. 43 (1) pp. 159-164.

Ayanoğlu, S.F. and Gündüz, G., 1978c, Neutron activation analysis of Turkish coals; III, Relation between composition of coal and local earth crust. Journal of Radioanalytical Chemisty v. 43 (1) pp. 165,167.

Bragg, L.J., Oman, J.K., Tewalt. S.J., Oman, C.L., Rega, N.H., Washington, P.M. and Finkelman, R.B., 1997. U.S. Geological Survey Coal Quality (COALQUAL) Database: Version 2.0 CD-ROM.

Demirok, Y., Uçakçıoğlu, A., 1993. Dünya'da ve Türkiye'de Linyit, Asfaltit, Taşkömür, Bitümlü şist, Uranyum Rezervleri ve Üretimleri. MTA, Fizibilite Etütleri Dairesi yayını. Ankara. p.37.

Dilli, B., 1999. ROUND TABLE Quality of Life Improvments Through Fossil Fuels Investment. Conference, Prospects for Cleaner Fossil Fuels, System in Sustainable development, Communicating their Strategic value in the Euro-Asian region. WEC, Turkish National Committe, May 26-29, Ankara, Turkey. p. 105-108.

Gökmen, V., Memikoğlu, O., Dağlı, M., Öz, D., Tuncalı, E., 1993. Türkiye Linyit Envanteri. MTA publication. Ankara. p.356.

Karayiğit, A.İ., Akgün, F., Gayer, R.A., Temel, A., 1999, Quality, palynology, and palaeoenvironmental interpretation of the Ilgin Lignite, Turkey. International Journal of Coal Geology. v. 38 (3-4) pp. 219-236.

Karayiğit, A.İ., Gayer, R.A., Querol, X., and Onacak, T., 2000a, Contents of major and trace elements in feed coals from Turkish coal-fired power plants. International Journal of Coal Geology v. 44 (2) pp.169-184.

Karayiğit, A.İ., Spears, D.A., and Booth, C.A., 2000b, Antimony and arsenic anomalies in the coal seams from the Gokler Coalfield, Gediz, Turkey. International Journal of Coal Geology v. 44 (1) pp. 1-17.

Karayiğit, A.İ., Spears, D.A., and Booth, C.A., 2000c, Distribution of environmental sensitive trace elements in the Eocene Sorgun coals, Turkey. International Journal of Coal Geology. v. 42 (4) pp. 297-314.

Querol, X., Alastuey, A., Plana, F., Lopez-Soler, A., Tuncalı, E., Toprak, S., Ocakoglu, F., Koker, A., 1999, Coal geology and coal quality of the Miocene Mugla Basin, southwestern Anatolia, Turkey, International Journal of Coal Geology. v41 pp. 311-332.

Querol, X., Whateley, M.K.G., Fernandez-Turiel, J.L., Tuncalı, E., 1997, Geochemical controls on the mineralogy and geochemistry of the Beypazarı lignite, central Anatolia, Turkey. International Journal of Coal Geology. v. 33 (3) pp. 255-271.

Palmer, C. A., Tuncalı, E., Finkelman, R.B., 1999, The distriburion of trace elements in Turkish lignites in Western Anatolia and the Thrace Basin, Proceedings of the 16th Annual International Pittsburgh Coal Conference. ISBN 1890977-16-0 CDROM. 49 p.

Tuncalı, E., Ocakoğlu, F., 1995. Türkiye'nin Kömür Potansiyeli, Rezervleri ve 21. Yüzyılda Kömür. Kömür Teknolojisi ve Kullanımı Semineri III, 13-14 Ekim, Yurt Madenciliğini Geliştirma Vakfı Yayınları, Ankara. p.19-26